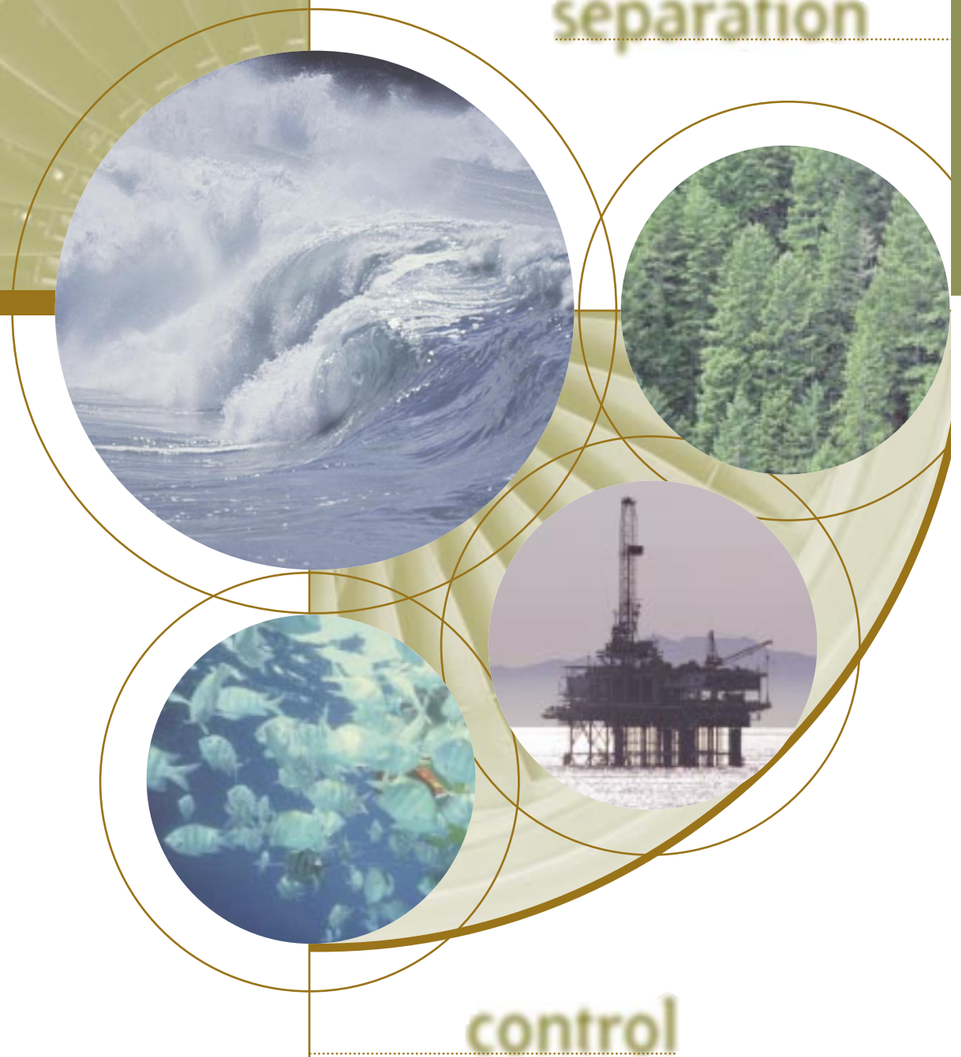
# CARBON SEQUESTRATION RESEARCH

PURSUING MID- AND LONG-TERM SOLUTIONS




CONCERNS ABOUT GLOBAL CLIMATE CHANGE DRIVE THE NEED TO DEVELOP LEADING-EDGE TECHNOLOGIES FOR COST-EFFECTIVE CARBON SEQUES-TRATION AND REUSE.

## PROGRAM AREAS

- System Studies and Assessments
- Enhanced Natural Sinks/ Offsets
- Capture and Separations Technology
- Geologic/Ocean Storage
- Chemical and Biological Fixation/Reuse

## INTRODUCTION

### NEW AND IMPROVED TECHNOLOGIES AT THE CORE OF DOE'S APPROACH

No single issue is as complex, or holds as many implications for the world's inhabitants, as global climate change. One of the primary environmental concerns of the 21st century, response to climate change could dictate fundamental changes in the ways in which we generate and use energy. Such measures as increasing energy efficiency, forest management options, and renewable energy applications are potentially important methods for reducing global greenhouse gas emissions in the short to medium term.

For the longer term, when much larger reductions may be sought, it is clear that additional technologies, including carbon sequestration, could be essential. The importance of carbon sequestration research has been underscored by the President's Committee of Advisors on Science and Technology (PCAST) report, *Federal Energy Research and Development for the Challenges of the Twenty-First Century*, November 1997. The PCAST report recommends increasing the U.S. Department of Energy's (DOE's) R&D for carbon sequestration. Specifically, the report recommends: "A much larger science-based $CO_2$ sequestration program should be developed.... The aim should be to provide a science-based assessment of the prospects and costs of $CO_2$ sequestration. This is very high-risk, long-term R&D that will not be undertaken by industry alone without strong incentives or regulations, although industry experience and capabilities will be very useful."

The Greenhouse Gas Sequestration portfolio concentrates on innovative sequestration concepts for longer-term solutions. It includes sequestration technologies for integration with Vision 21 plants at an energy facility site and approaches to remove carbon dioxide from the atmosphere by the enhancement of natural sinks to create greenhouse gas reduction credits.

The program addresses novel and advanced concepts for:

- Cost-effective $CO_2$ capture and separation processes
- Geologic storage options, including those that recycle carbon back to its source in natural formations
- Enhancement of natural processes in terrestrial and ocean sinks to complement point-source sequestration that is directly associated with energy production
- Chemical or biological fixation or reuse

A recent study by the Massachusetts Institute of Technology evaluated and prioritized research needs for the capture, use, and storage of $CO_2$ from fossil-fuel-fired powerplants (Herzog, Drake, Adams—*$CO_2$ Capture, Reuse, and Storage Technologies for Mitigating Global Climate Change*, January 1997). Based upon current assessments, the potential for sequestration is quite high but largely unexamined. In the United States, very little research and development has been done on promising options that might address these pathways.

## BENEFITS TO THE NATION

***Energy security***. Effective carbon sequestration and reuse technologies will enable the U.S. to depend upon its vast and inexpensive domestic resources of coal, which now provide 55% of all electricity produced, and still satisfy environmental concerns.

***Growth of U.S. industry.*** Development of a portfolio of innovative, cost-effective sequestration technologies will keep energy prices low and thus help the U.S. to remain a world economic leader.

***Market competitiveness.*** Development of sequestration technologies will also enable the U.S. to compete in, and likely lead, a new global market for an entirely novel class of technologies.

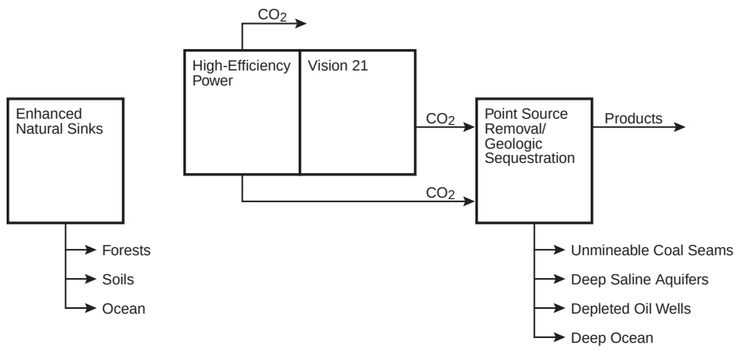
## STRATEGIES FOR SUCCESS

The overall goal of the program is to develop a set of sequestration options with potential to offset all new growth in greenhouse gas emissions beginning in the year 2015, and to verify the environmental acceptability, technical feasibility, and cost-effectiveness of a sequestration capacity sufficient for wide-scale implementation starting in 2015.

During the 2005 to 2015 time period, a suite of cost-effective options with increasingly large carbon sequestration capacity will be made available. The program will seek to develop even lower-cost options by 2020, capable of sequestering carbon at a cost of $10/ton. The strategy for achieving this goal is to build upon ongoing scientific, technical, and environmental research using domestic and international cost-shared collaborations with industry, universities, and other governments (e.g., the International Energy Agency [IEA] Greenhouse Gas R&D Programme, the Climate Technology Initiative of the Framework Convention on Climate Change [Working Group 3], and other agreements). In addition, the Offices of Fossil Energy and Energy Research (ER) have established a formal working group to coordinate carbon-management science and sequestration technology research. DOE's program has also received considerable input from industry, government, and academic stakeholders via expert workshops held during the summer of 1998.

*DOE's $CO_2$ sequestration portfolio aims to remove $CO_2$ efficiently from fossil fuel production and use and to store it for geologic time. Higher-efficiency powerplants will emit less $CO_2$; cost-effective Vision 21 plants will emit no net $CO_2$. Point-source sequestration and distributed sequestration, including enhancement of natural processes, will reduce $CO_2$ emissions and atmospheric concentrations.*

### COMBINED PORTFOLIO BENEFITS






CARBON SEQUESTRATION RESEARCH

Further workshops on specific areas of sequestration research, such as geologic sequestration, are being conducted during FY 1999.

The challenge for the future is to expand the current collaborative industry-university-government R&D partnerships that result in cost-effective, innovative technologies to complement and enhance natural sequestration processes.

The program emphasizes competitive, cost-shared solicitations to create partnerships. The first of these competitive solicitations, issued in FY 1998, selected 12 innovative novel concepts for the control of atmospheric emissions of $CO_2$, methane ($CH_4$), and nitrous oxide ($N_2O$). Sequestration-related topics are included in the Department's Small Business Innovation Research, University Coal Research, and Small Business Technology Transfer Program solicitations.

## SYSTEM STUDIES AND ASSESSMENTS

A wide variety of activities are used to identify and assess promising novel and advanced concepts for sequestration technologies and the evolving technologies necessary to support them. Activities include system studies; exploratory research; technical, economic, and environmental assessments; full fuel-cycle analyses; expert workshops; and outreach activities to seek promising new ideas and to communicate findings and results to industry, academia, and the public.

## ENHANCED NATURAL SINKS/OFFSETS

The annual exchange of $CO_2$ between the atmosphere and the combined ocean and terrestrial biosphere is extremely large compared to total annual anthropogenic emissions. This suggests that small increases in the net absorption of $CO_2$ in the global carbon cycle could have a significant effect on changes in atmospheric greenhouse gas concentration.

Dissolved $CO_2$ in the oceans is removed by the growth of phytoplankton, with plant decay products settling to the deep ocean or ocean bed. When carbon is thus removed, it is ultimately replaced by $CO_2$ drawn from the atmosphere. Numerous concepts have been proposed for enhancing oceanic uptake of atmospheric $CO_2$.

### A TIMELINE TO ACCOMPLISH THE GOAL

***FY 1998.*** Feasibility investigations of 12 novel concepts for greenhouse gas sequestration were initiated. International collaborative research in ocean sequestration activity is under way with Japan and Norway. An industry-government partnership addressing sequestration in deep, unmineable coal seams was initiated in collaboration with the IEA Greenhouse Gas R&D Programme. A comprehensive update of the assessment of research needs for $CO_2$ sequestration was completed.

***FY 1999.*** Comprehensive $CO_2$ sequestration research roadmapping is being completed. The second phase of novel concepts investigations—to obtain the required engineering and economic data to proceed to proof-of-concept—is scheduled to begin.

***By 2010.*** In partnership with industry and international partners, DOE will establish the viability of a large capacity of sequestration approaches suitable for deployment by industry in the longer-term (post-2015) time frame.

An important component of terrestrial uptake of $CO_2$ is tree and plant growth. Trees can remove carbon from the atmosphere and sequester it in forests and forest products, whereas deforestation reduces the amount of carbon sequestered. Through improved forest-management technologies, substantial increases can be made in carbon sequestration by (1) halting deforestation, (2) expanding forests and reforesting areas, and (3) increasing the stocks of carbon in existing forests.

A recent study by the IEA Greenhouse Gas R&D Programme has confirmed that there are potentially large, cost-effective, forest sequestration opportunities. However, to achieve potential benefits, barriers to the application of advanced forest-management technologies must be overcome.

Carbon sequestration in soils is also a key part of the carbon cycle. In this area, research is needed to develop practical and economic technology approaches to increasing soil organic matter and to inexpensively monitor changes in it.

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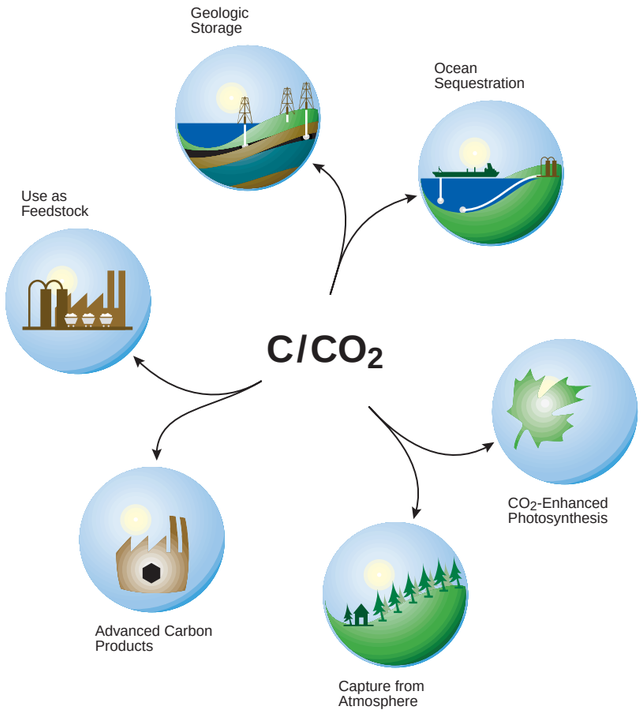


## CAPTURE AND SEPARATIONS TECHNOLOGY

Sequestration from large point sources requires cost-effective capture of carbon, whether it is $CO_2$ or C, and its separation from other constituents not destined for sequestration. Capture and separation technology is available but is costly and inefficient.

The focus of this program area is the development of innovative concepts to address improvements in the technical and economic performance of existing technologies.

*Carbon sequestration is the separation and capture of $CO_2$ for either geologic storage, enhancement of natural sinks, or chemical and biological fixation/reuse. It includes disposal either as $CO_2$ or as some other form of carbon. More than just storage, it includes both existing and new commercial uses of $CO_2$, CO, and C.*





## GEOLOGIC/OCEAN STORAGE

Another set of promising concepts for reducing $CO_2$ concentrations pertain to its storage in geologic formations. It is believed that $CO_2$ could be cost-effectively sequestered in these formations.

Options for geologic storage of $CO_2$ include sequestration in depleted or depleting oil or gas wells, coal seams, or deep underground saline formations. Statoil of Norway is currently sequestering $CO_2$ in a deep saline reservoir under the North Sea, the first practical project of this method of sequestering $CO_2$. Critical research questions center on understanding the effects of $CO_2$ on the chemical and physical properties of storage sites, environmental impacts, total potential storage capacity, and the economics of various candidate sites.

Similar carbon storage has already taken place for over a decade at more than 70 enhanced oil recovery sites around the world, where $CO_2$ injection is used to augment traditional oil recovery technologies.

Research is being conducted to answer the most critical technical questions about the feasibility of and capacity for ocean storage of $CO_2$ captured from combustion processes.

## CHEMICAL AND BIOLOGICAL FIXATION/REUSE

Advanced chemical and biological sequestration is aimed at permanent, stable sequestration and at recycling carbon to create new fuels, chemical feedstocks, and other products. Research is being conducted to develop novel concepts to convert $CO_2$ , CO, or C into environmentally benign, economically useful products. The major advantage of these technologies is that they produce economically valuable products for the global economy while meeting a global environmental goal. All concepts for these technologies are at an early research stage. Better understanding of the basic processes and new chemistry and bioprocessing approaches is needed before practical, achievable technology performance or cost levels can be estimated.

### CHEMICAL AND BIOLOGICAL PATHWAYS FOR CARBON SEQUESTRATION

- Conversion of CO to new carbon-based products
- Chemical sequestration as a carbonate mineral
- Direct conversion of $CO_2$ into methanol or other products
- Decarbonization of fossil fuels with the capture of excess carbon
- Microalgae sequestration
- Biomimetic fixation of carbon